

Laboratory and Field Tests of Hardness and Wear Resistance of Heat-Treated Steel Samples and Machine Parts

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Abstract: This article describes the method of testing the hardness and wear resistance of hardened and released steel samples and machine parts in laboratory and field conditions. Samples with wear-resistant carbide coating obtained by casting according to expanded polystyrene gasified models are presented. The compositions, properties and abrasive wear resistance of cast steel samples before and after heat treatment with double phase recrystallization were studied. It is shown that heat treatment with double phase recrystallization increases the hardness and wear resistance of cast samples and parts by 2-3 times higher than serial ones.

Keywords: foam model, cast samples, carbide coating, heat treatment with double phase recrystallization, hardening, tempering, microstructure, hardness and abrasive wear resistance of samples and parts.

Introduction. One of the most important tasks of agricultural engineering is to improve the operational properties and qualities [1], as well as to extend the service life of parts of machines and mechanisms [2]. This requires the widespread use of durable and wear-resistant materials based on a hard alloy of the PG-S27 sormite type, as well as the introduction of new modern technological methods that improve the operational properties and increase the service life of machinery and equipment parts [3].

Machines used in metallurgical and automotive and agricultural machine-building have grown out of order due to intense abrasive-corrosive or shock-abrasive wear [4,5] of the main parts of machines and mechanisms. One of the simplest and most effective ways to extend the life of agricultural machinery parts is to manufacture them from wear-resistant hard alloys of the PG-C27 sormite type by casting on expanded polystyrene gasified [6] models.

This article presents materials on the study of hardness and abrasive wear resistance of structural carbon steels.

As studies have shown, the resistance of metals to abrasive wear [7] depends primarily on their chemical composition and mechanical properties, as well as optimal heat treatment. At the same time, wear resistance is closely related to the hardness of structural components and will be higher the higher their hardness and the more solid components in the alloy. Therefore, the abrasive wear resistance of steels can be significantly increased by alloying solid solutions and creating special carbides M_7C_3 , $M_{23}C_6$ and etc.

The available data on the hardness and wear resistance of various steels [8,9] in an abrasive medium are insufficient for generalizations, so we had to study different grades of steels in order to identify on this basis the relationship between the abrasive wear resistance of steel, its chemical composition, property and microstructure of steel [10].

Knowledge of such patterns would make it possible to reasonably choose the steel grade and prescribe the optimal heat treatment for machine parts operating in severe conditions of abrasive wear.

Methodology of the study. The following steel grades were selected for the study: medium-carbon (steel 20, 25, 30, 35GL, 45L) and potassium permanganate (steel 65G).

For the study, steels in an annealed and hardened state with diameters of 70x30x15 and 70x35x15 were chosen. The dimensions and shape of the samples for abrasive wear are presented in fig.1,a,b. The abrasive wear test was carried out on the friction machine PV-7 fig.1,d.

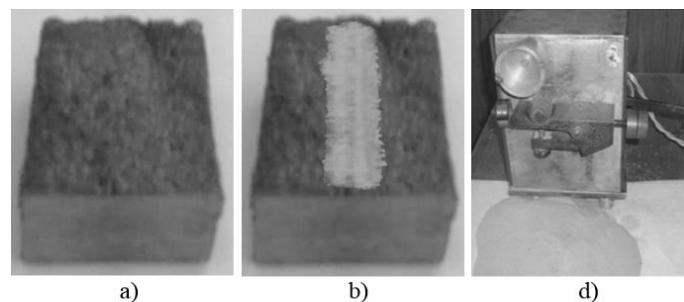


Fig.1. Special samples with a carbide coating thickness of 2.0-2.5 mm for abrasive wear test: **a**-state before testing; **b**-after testing; **d**-general view of the friction machine PV-7.

The chemical composition of steels is given in table 1. From all the steels indicated in it, special samples were made for testing for abrasive wear. For this purpose, samples from carbon steel (20,25,30) and cast samples from high-quality medium-carbon steel (35GL,45L) obtained by casting according to expanded polystyrene gasified models, as well as from potassium permanganate quality steel (65G) were selected and subjected to various heat treatment modes (hardening from 820⁰ to 825⁰C) and (release from 180⁰ to 200⁰C) [11].

Table 1. Chemical composition of the studied steels

Steel grade	Content of elements, in % (not more)						
	C	Si	Mn	Cr	Ni	P	S
carbon steels							
20	0,17-0,24	0,17-0,37	0,35-0,65	0,25	0,25	0,040	0,040
25	0,22-0,29	0,17-0,37	0,50-0,80	0,25	0,25	0,040	0,040
30	0,27-0,34	0,17-0,37	0,50-0,80	0,25	0,25	0,040	0,040
medium carbon and potassium permanganate quality steels							
35ГЛ	0,32-0,39	0,17-0,37	0,70-0,95	0,28	0,27	0,040	0,040
45Л	0,42 - 0,5	0,17 - 0,37	0,5 - 0,8	0,25	0,25	0,035	0,040
65Г	0,62-0,70	0,17-0,37	0,90-1,20	0,28	0,27	0,040	0,040

Research results and their discussion. All carbide-coated samples before and after thermal treatment with double phase recrystallization were tested for hardness and abrasive wear resistance [2,3]. These samples were tested for abrasive wear on a PV-7 friction machine with loose abrasive material. The test time for each steel sample is 30 min. For experimental cast samples with a carbide coating, the tests were repeated 5-6 times, and for standard samples (steels) - 6-8 times. Carbide coating dramatically increases hardness and abrasive wear resistance: the greater the thickness of the coating, the lower the wear value. The results of testing the abrasive wear of samples made of steel 20,25,30 and cast sample 35GL,45L, as well as 65G before and after heat treatment are given in table 2-3.

Table 2. Abrasive wear of carbon steels

№	Steel grade	Time tests, min	Wear before the test, G	Wear after the test, G	Wear difference before and after the test, G
Abrasive wear of carbon steel No.01 before heat treatment					
1.	20	30	141,2470	141,2438	0,0032
2.	20	30	141,2438	141,2409	0,0029
3.	20	30	141,2409	141,2385	0,0024
4.	20	30	141,2385	141,2368	0,0017
5.	20	30	141,2368	141,2355	0,0013
6.	20	30	141,2355	141,2346	0,0009
7.	20	30	141,2346	141,2341	0,0005
8.	20	30	141,2341	141,2341	0,0000
Abrasive wear of carbon steel No.02 before heat treatment					
1.	25	30	142,2038	142,2009	0,0029
2.	25	30	142,2009	142,1985	0,0024
3.	25	30	142,1985	142,1967	0,0018
4.	25	30	142,1967	142,1952	0,0015
5.	25	30	142,1952	142,1942	0,0010
6.	25	30	142,1942	142,1936	0,0006
7.	25	30	142,1936	142,1933	0,0003
8.	25	30	142,1933	142,1933	0,0000
Abrasive wear of carbon steel No.03 before heat treatment					
1.	30	30	143,4390	143,4364	0,0026
2.	30	30	143,4364	143,4342	0,0022
3.	30	30	143,4342	143,4326	0,0016
4.	30	30	143,4326	143,4314	0,0012
5.	30	30	143,4314	143,4305	0,0009
6.	30	30	143,4305	143,4299	0,0006
7.	30	30	143,4299	143,4295	0,0004
8.	30	30	143,4295	143,4295	0,0000
Abrasive wear of cast sample No. 1 with a coating thickness of 2.0 mm before heat treatment					
1.	35ГЛ	30	144,4092	144,4074	0,0018
2.	35ГЛ	30	144,4074	144,4059	0,0015
3.	35ГЛ	30	144,4059	144,4048	0,0011
4.	35ГЛ	30	144,4048	144,4041	0,0007
5.	35ГЛ	30	144,4041	144,4037	0,0004
6.	35ГЛ	30	144,4037	144,4037	0,0000
Abrasive wear of cast sample No. 2 with a coating thickness of 2.5 mm before heat treatment					
1.	45Л	30	144,5093	144,5076	0,0017
2.	45Л	30	144,5076	144,5062	0,0014
3.	45Л	30	144,5062	144,5051	0,0011
4.	45Л	30	144,5051	144,5044	0,0007
5.	45Л	30	144,5044	144,5040	0,0004
6.	45Л	30	144,5040	144,5040	0,0000
Abrasive wear of manganese steel No. 04 before heat treatment					
1.	65Г	30	144,4091	144,4072	0,0019
2.	65Г	30	144,4072	144,4056	0,0016
3.	65Г	30	144,4056	144,4044	0,0012
4.	65Г	30	144,4044	144,4037	0,0007

5.	65Г	30	144,4037	144,4034	0,0003
6.	65Г	30	144,4034	144,4034	0,0000

The results of the abrasive wear test of samples after heat treatment are given in table 3.

Table 3. Abrasive wear of carbon steels

№	Steel grade	Time tests, min	Wear before the test, G	Wear after the test, G	Wear difference before and after the test, G
Abrasive wear of carbon steel No.01 after heat treatment					
1.	20	30	138,6283	138,6267	0,0016
2.	20	30	138,6267	138,6256	0,0011
3.	20	30	138,6256	138,6247	0,0009
4.	20	30	138,6247	138,6241	0,0006
5.	20	30	138,6241	138,6237	0,0004
6.	20	30	138,6237	138,6235	0,0002
7.	20	30	138,6235	138,6235	0,0000
Abrasive wear of carbon steel No.02 after heat treatment					
1.	25	30	138,5685	138,5671	0,0014
2.	25	30	138,5671	138,5660	0,0011
3.	25	30	138,5660	138,5652	0,0008
4.	25	30	138,5652	138,5646	0,0006
5.	25	30	138,5646	138,5642	0,0004
6.	25	30	138,5642	138,5640	0,0002
7.	25	30	138,5640	138,5640	0,0000
Abrasive wear of carbon steel No.03 after heat treatment					
1.	30	30	137,7090	137,7077	0,0013
2.	30	30	137,7077	137,7066	0,0011
3.	30	30	137,7066	137,7058	0,0008
4.	30	30	137,7058	137,7052	0,0006
5.	30	30	137,7052	137,7048	0,0004
6.	30	30	137,7048	137,7046	0,0002
7.	30	30	137,7046	137,7046	0,0000
Abrasive wear of cast sample No. 1 with a coating thickness of 2.0 mm after heat treatment					
1.	35ГЛ	30	140,4477	140,4472	0,0005
2.	35ГЛ	30	140,4472	140,4469	0,0003
3.	35ГЛ	30	140,4469	140,4467	0,0002
4.	35ГЛ	30	140,4467	140,4466	0,0001
5.	35ГЛ	30	140,4466	140,4466	0,0000
Abrasive wear of cast sample No. 2 with a coating thickness of 2.5 mm after heat treatment					
1.	40ГЛ	30	140,4678	140,4672	0,0006
2.	40ГЛ	30	140,4672	140,4668	0,0004
3.	40ГЛ	30	140,4668	140,4666	0,0002
4.	40ГЛ	30	140,4666	140,4665	0,0001
5.	40ГЛ	30	140,4665	140,4665	0,0000
Abrasive wear of manganese steel No. 04 after heat treatment					
1.	65Г	30	140,4880	140,4871	0,0009
2.	65Г	30	140,4871	140,4864	0,0007
3.	65Г	30	140,4864	140,4861	0,0003
4.	65Г	30	140,4861	140,4860	0,0001
5.	65Г	30	140,4860	140,4860	0,0000

As can be seen from table. 2-3, our tests for abrasive wear of samples with a coating layer thickness of 2.0 and 2.5 mm fully correspond to the results of field tests (table 4), which really increase the hardness and wear resistance of cast steel parts after heat treatment with double phase recrystallization by two and three times [10,11].

Based on the studies performed, four batches of experimental parts of 20 pieces in each batch were manufactured for field tests. The first batch was made according to serial technology from steel 20, the second - from steel 35GL without carbide coatings, the third - from steel 35GL with wear-resistant carbide coating, the fourth - from steel 35GL with wear-resistant carbide coating after heat treatment with double phase recrystallization [3]. The amount of wear of samples was determined by weight, after the work of the cultivator for time to process 150-230 hectares of sown hectares. The relative wear resistance of samples compared to serial parts was also determined. Field tests were conducted in different regions (districts) of the Republic of Uzbekistan and almost identical results were obtained (Table 4). In addition, along with these parts (samples), cast needle rotary sprockets of agricultural machines, small ploughshares of a deep-digger and a cotton knife made of carbon steel were tested in the laboratory and field, which received the same similar test results [6].

Table 4. Field test results

No	Brands of tested parts	Relative wear resistance
1.	Serial steel 20	1,0
2.	Experimental uncoated steel 35GL	1,2
3.	Experimental coated steel 35GL	1,5-2,0
4.	Experimental steel 35GL coated after heat treatment with double phase recrystallization	2,5-3,0

In accordance with the task, the purpose of this work is to develop a technology for obtaining expanded polystyrene models and cast parts with high abrasive wear resistance. The object of research was the details of metallurgical and tillage machines, such as harrow teeth, naralnik, cultivator paws, needle rotary stars, deep-baking ploughshares, cotton embossing knife, and rollers of metallurgical rolling equipment, experiencing intense abrasive wear when sliding on soil and metal [6]. The structure of carbon steels in the initial annealed state consists of ferrite and ferrite-perlite and the smallest amount of residual austenite (fig.2,a,b,d).

The paper examines the composition of wear-resistant hard alloys of the sormite type. The choice of the composition of the applied coating was made according to two criteria: The 1-coating must meet the requirement of a 3-5-fold increase in wear resistance compared to the wear resistance of the steel base; 2-coating should include available and inexpensive components and be distinguished by the simplicity of its application technology.

Based on this, hard alloys of the sormite type PG-S27 were chosen as a coating on the working surface of the part. This alloy increases hardness and wear resistance and is especially effective in conditions of abrasive wear. When pouring the metal, the foam model burns out, and the surface of the casting was saturated with carbon up to 0.7% to a depth of 0.30.6 mm. When the coating of sormite powders comes into contact with liquid metal, a solid casting crust is formed. Then the coating was melted and after crystallization on the surface of the casting, a wear-resistant carbide coating was formed with a layer thickness of 2.0-2.5-3.0 mm and with the structure [6] of a high-alloy alloy of eutectic and hypereutectic composition (fig.2,e,f,g). As a result of heat treatment, the surface layer should have the structure of finely acicular granular martensite (fig.3) with fine carbide or isolated areas (the smallest amount) of residual austenite.

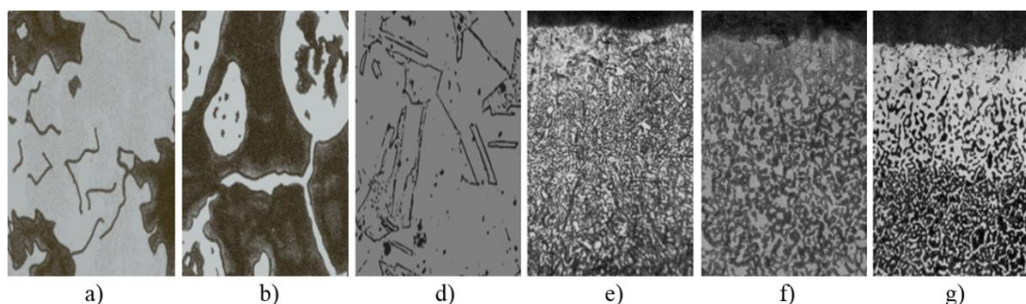


Fig.2. Microstructure of carbon steel samples: a-ferritic structure; b-ferrite-perlite structure; d-least residual austenitic; e-wear-resistant carbide coating with a layer thickness of 2.0 mm; f-2.5 mm; g-3,0 mm. X500

Thus, a multilayer composition was formed on the working surface, consisting of a high-alloy layer of an alloy of hypereutectic and eutectic composition, passing in depth into the zones of hypereutectic and eutectoid steel and the base metal of steel 35GL. To check the surface thickness of the casting layer, a finished part with a wear-resistant carbide coating was taken, a piece of grinding for macro and micro-studies was cut, then it was polished and polished, and then washed and etched with a special etching agent to detect a surface carbide coating with a thickness of the coating layer from 2 to 4 mm.

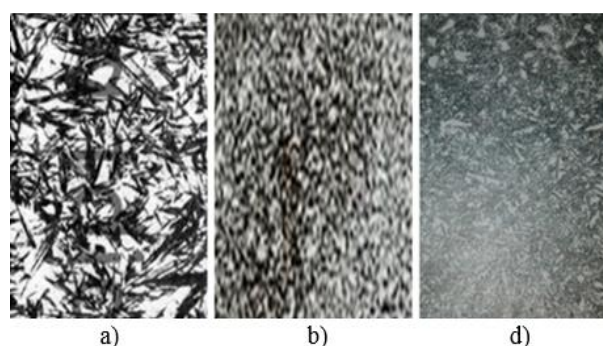


Fig.3. Microstructure of heat-treated carbon steels: a-coarse-needle martensite; b-fine-needle martensite; d-hardened structure of martensite with inclusions of globular fine carbides. X500

More clearly and visually, the macro image of surface carbide ‘sormite’ coatings from the cut samples is presented in (fig.4a,b,d,e). The hardness of the surface layers of samples and finished parts is HRC58-62, and the microhardness reaches up to 1800-2200HV (fig.4,f). The results of the study show that after heat treatment (hardening and tempering) of samples obtained during casting according to gasified [6] models with inserts of a layer thickness of 2.0 and 2.5 mm, compared to the initial cast state, the location and shape of the carbides in the hypereutectic and eutectic zones did not change (see fig.4,f). However, a heating temperature of 900°C was sufficient to form a martensitic structure in areas with a perlite component. This structure increases the hardness and wear resistance of parts by two and three times [11,12].

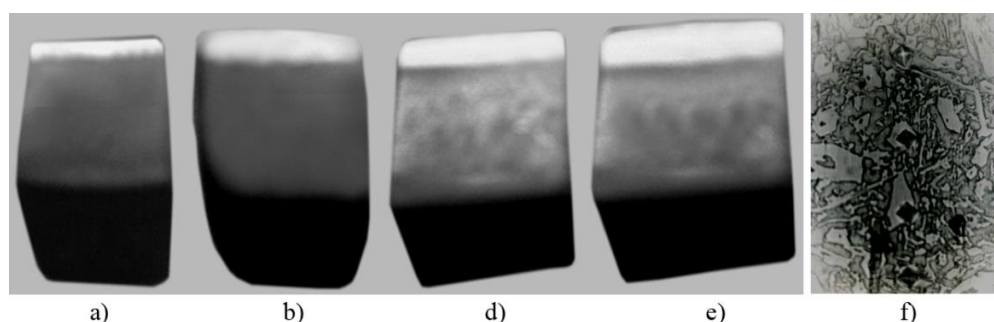


Fig.4. Specially prepared steel samples with wear-resistant carbide coating of Sormite type with layer thickness: a-2.0 mm; b-2.5 mm; d-3.0 mm; e-4,0 mm; f-microhardness of the surface coating.

Findings. In connection with the above, the most effective way to increase hardness and abrasive wear resistance is to apply a carbide coating to the working surfaces of the product during casting on gasified models and subsequent heat treatment with double phase recrystallization. This treatment forms an optimal structure with a high density of locations, dispersed secondary and coagulated primary carbides, as well as a martensitic structure of a solid alloy coating made of sormite type hard alloy. Optimal heat treatment with double phase recrystallization increases the hardness and abrasive wear resistance of cast samples and machine parts by 2-3 times higher compared to serial products. This innovative technology was introduced in JSC "Uzmetkombinat" and JSC "Aggregate Plant" with a good economic effect and an act of implementation was obtained on the application of this technology in production.

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